The new infrared imaging system on Alcator C-Mod

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Abstract

A new infrared imaging system has been installed on Alcator C-Mod. This system uses an Amber Radiance 1 IR video camera (filtered to the 4.2-4.4 μm band) to view a 30 cm × 30 cm region of the lower divertor from above by means of a re-entrant 5-m long ZnSe based periscope. The capture of the 30 Hz standard video frames (8-bit) and camera control are preformed remotely through fiber optic links by a Windows 95 PC and using a MuTech MV-1000 video grabber board. Plans are underway to capture directly the 60 Hz, 12-bit, 256 × 256 pixel images using a digital video camera interface with fiber optic link from EDT (Beaverton, Oregon). Preliminary results show that during non-disruptive discharges no substantial surface temperature increase is observed on the upper sections of the divertor, with the exception of "hot spots", although occasionally increased heating in toroidal bands is seen. Also, after disruptions that result in a downward movement of the plasma, heating is observed both in toroidal bands and on individual tiles.

Introduction

- **Issues**
  * Measure temperatures of divertor surfaces.
  * Search for hot spots, possible sources of molybdenum.
- **Approach**
  * Use an Amber Radiance 1 video camera sensitive in the mid IR range: 3-5 μm.
  * Use an IR periscope to view the lower, closed divertor and locate the IR camera where the magnetic field is manageable.
  * Capture the standard video output of the IR camera with a MuTech MV-1000 PCI video grabber board located in a PC running Windows 95.
- **The IR periscope**
  * Use ZnSe lenses and wedges to transport the image a distance of ~5 m.
  * Design optimized with ZEMAX-SE ray tracing code.
- **Results**
  * A 30 cm x 30 cm region of the divertor is imaged with spatial resolution better than a millimeter.
  * No substantial surface temperature increase is observed on the upper sections of the divertor, with the exception of “hot spots”, although occasionally increased heating in toroidal bands is seen.

Amber Radiance 1 IR camera

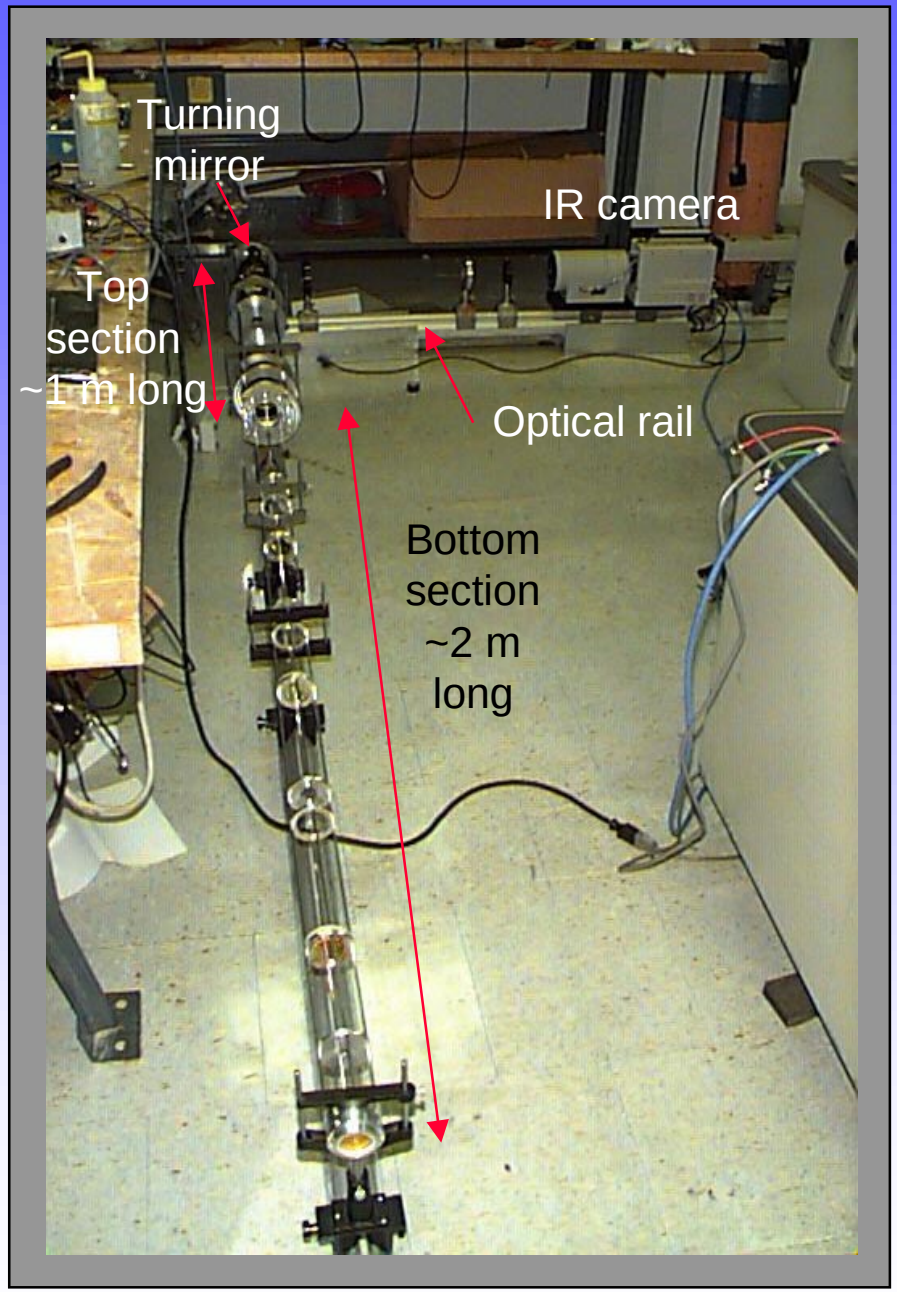
- 256 x 256 Indium-Antimony sensor array.
- Gated from 1 μs to 16 ms.
- Full remote control through RS-232 link.
- 2.23°/7.4° Dual Field of View lens.
- Filter wheel with **narrowband (4.28-4.42 μm)** or 10%, 1% , and 0.1 % neutral density filters.
- **NTSC (RS-170)**, S-Video or 12 bit digital output.

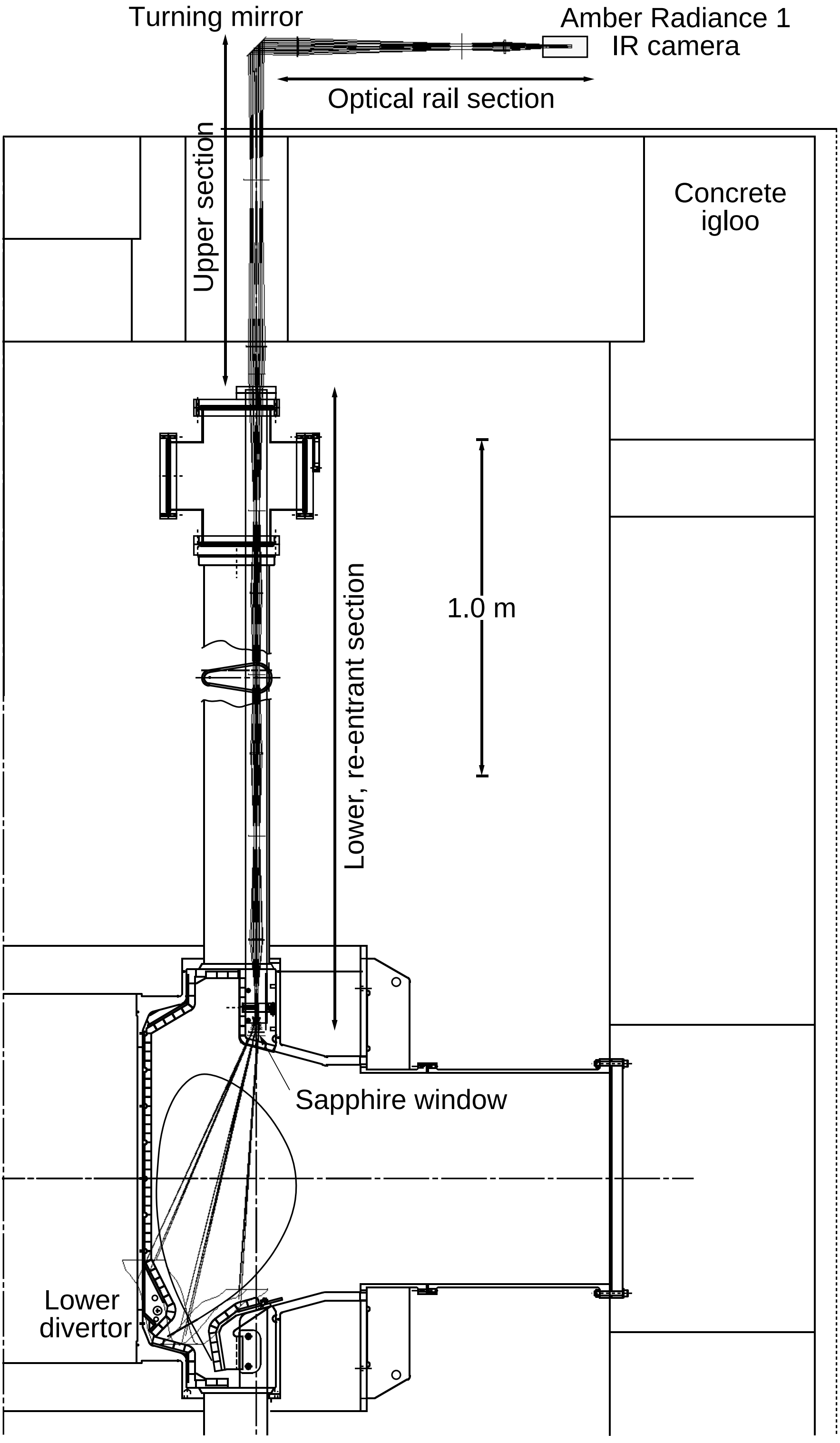
IR camera control and data acquisition

- A 100 MHz Pentium PC located in C-Mod's control room and running Windows 95 is used to capture and store the IR images, as well as control the IR camera.
- A fiber optic video link transmits the standard NTSC output of the IR camera from the test cell to the control room. The RS-232 remote control of the IR camera is also achieved through fiber optic links.
- A MuTech MV-1000 PCI video grabber board is used in the 100 MHz PC to capture the IR images. An external trigger supplied to this board allows the data to be synchronized with the experiment.
- A Windows C^{++} program developed by PSFC-MIT is used to control the video grabber board and store the data. This program can also replay captured and/or stored video clips.
- The data can be stored in several formats: JPEG, GIF and Motional GIF. The MGIF files can then be transferred to the DEC cluster for analysis with IDL.
- As a backup, the video signal from the IR camera is also stored in NTSC/VHS video tape.

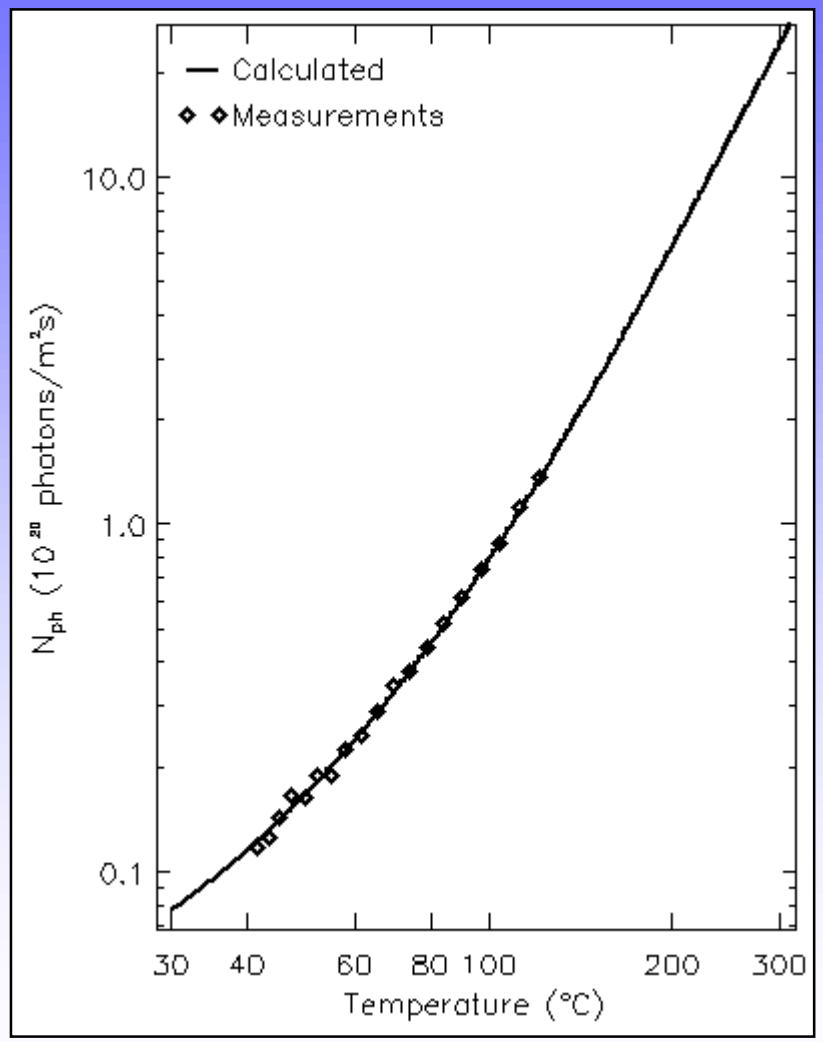
IR periscope

- The periscope is composed of:
  * 7 lenses and 4 wedges (ZnSe with AR coating for 3-5 μm band)
  * Al & SiO coated turning mirror.
- The periscope is assembled and focused on the floor (a.k.a. bench). (**FIGURE**)
- The bottom assembly is then inserted downward in the A top re-entrant tube of Alcator C-Mod (2.5" OD). The top assembly is placed through the igloo cover and the optical rail (with the IR camera) is secured on top of the igloo.
- The vacuum interface is accomplished by sapphire window.
- Once inserted in Alcator C-Mod the bottom section is rotatable in 45º steps for increased surface coverage.




Turning mirror
Amber Radiance 1
IR camera
Optical rail section
Upper section
Concrete
igloo
1.0 m
Lower, re-entrant section
Sapphire window
Lower
divertor

Calculated hemispherical blackbody emission in the 4.24-4.42 μm band



- The measurements were obtained with a molybdenum tile with appropriate scaling and hot element (lens) offset.
- The good agreement in the functional form indicates that in the 40-140 ºC range the tile emissivity is not a sensitive function of the temperature.
- This behavior is then extrapolated along the calculated, constant emissivity, curve up to the 200-300 ºC range.
- The (hot element) background photons represent, for instance, ~92% of the photons detected at 80 ºC.

Divertor image in typical RF heated discharge

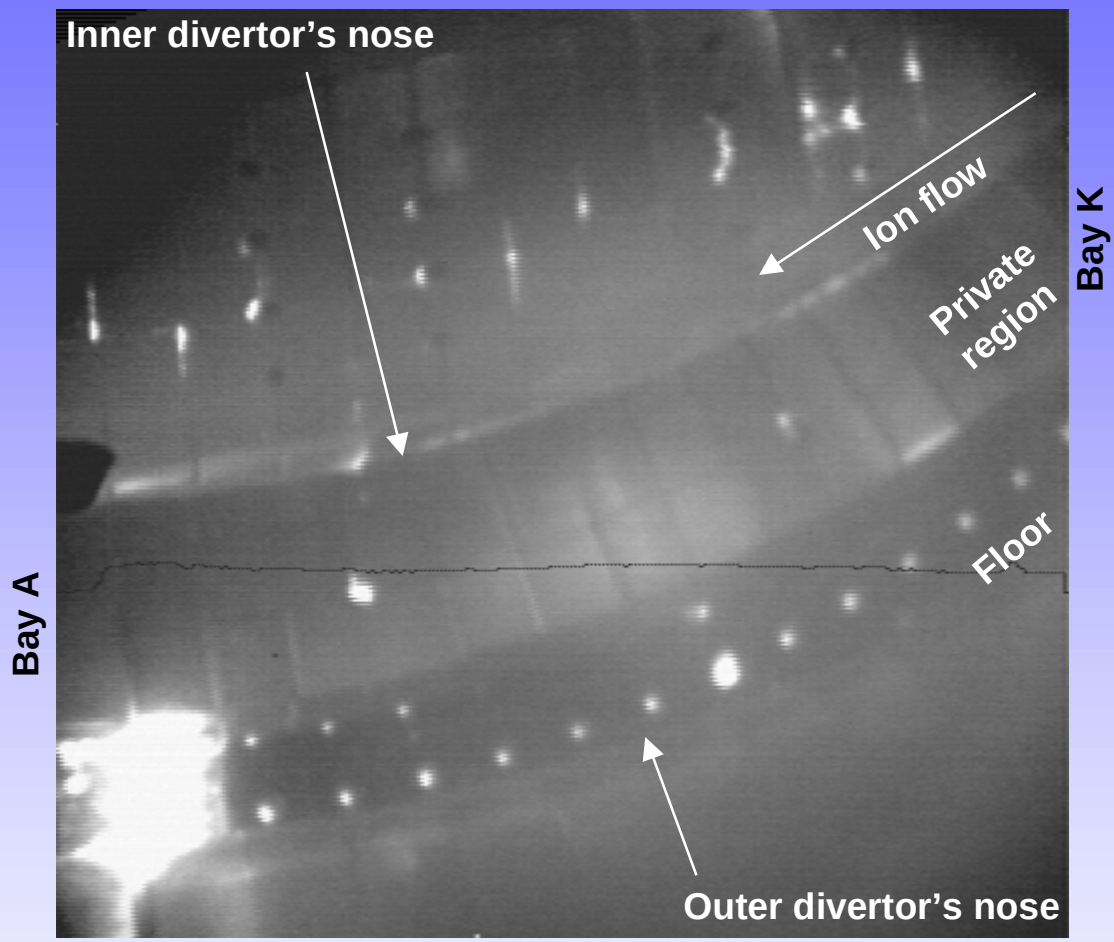


Image obtained with Amber Radiance 1 IR camera using the 4.28-4.42 μm bandpass filter and 1.04 ms exposure

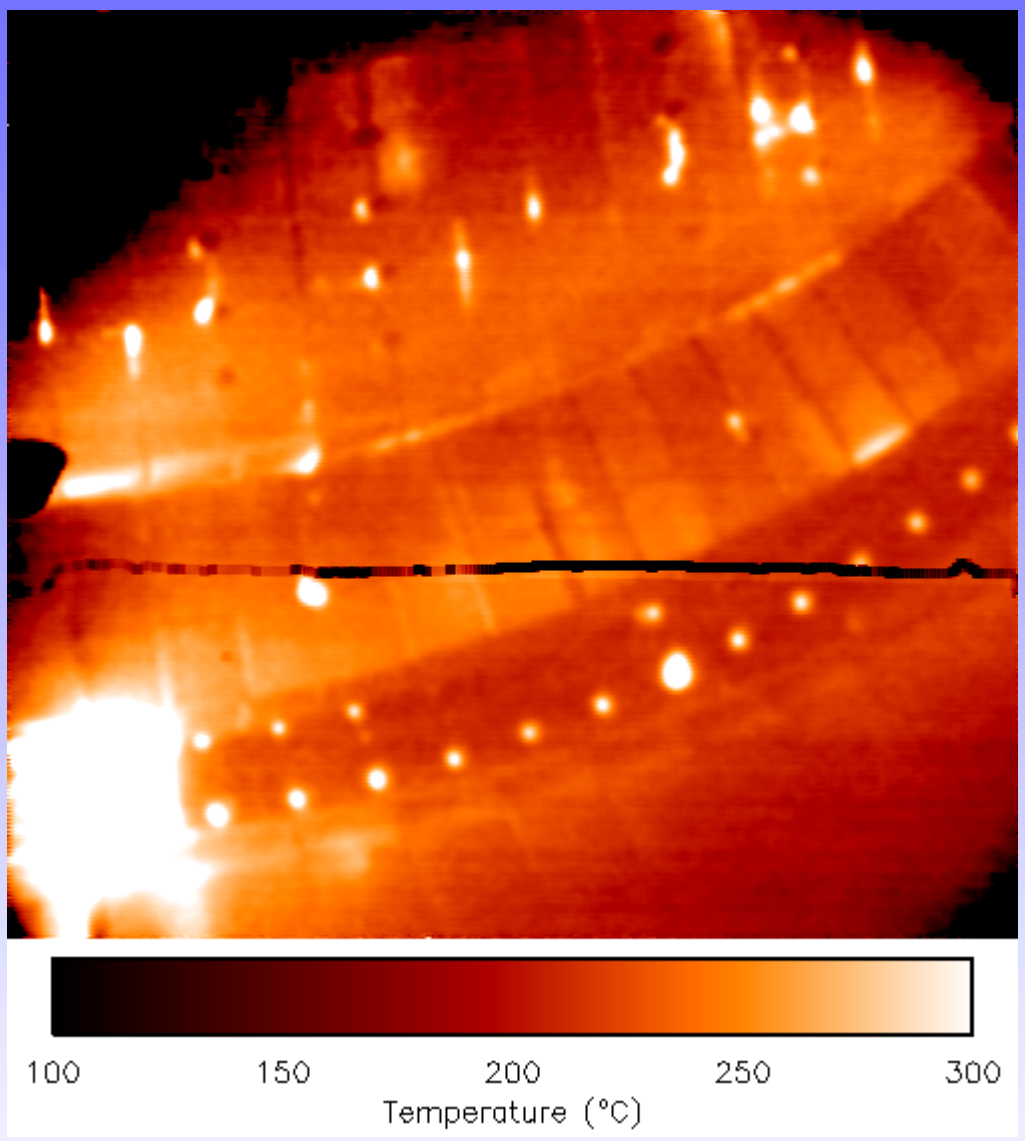
Observations

- No localized heating in toroidal bands is observed, just hot spots.
- These hot spots correspond to either edges around depressions, like those observed on the inner divertor nose, or to slightly protruding elements such as the big hot spot on the floor at Bay A, a turning mirror for another diagnostic.
- The line of hot spots along the floor are not such but recessed silver-plated bolts. These bolts apparently reflect intense IR thermal radiation from the surface below the outer divertor nose, hidden to the camera.
- The dark line across the image near its midplane corresponds to a lineup reading of the InSb sensors located the midplane of the image.
- The dark spot at the image midplane, Bay A edge, corresponds to a cold (room temperature) fiducial placed in an intermediate image plane.

Calibration process

- The image intensities are converted into photon counts by means of the lineup trace inserted on the image by the Amber Radiance camera. This relies also on the two point non-uniform pixel correction capability of the Amber camera.
- The photon counts are then corrected for photon losses (absorption and reflection) in the periscope and difference in collection angle between measurement and camera calibration with the molybdenum tile.
- A scaled “constant emissivity” curve (camera calibration) is used for each of the pixels in the image to turn corrected photon counts into temperatures.
- The resulting error is of the order of 40 ºC, mainly due to the small relative amount of surface temperature photons respect to background (hot element) photons and uncertainties in the periscope transmission.

Divertor temperatures in typical RF heated discharge



The divertor region heats up only to the 250 ºC range after substantial ICRF heating (~1.8 MJ)

Heating in a toroidal band observed in Helium discharge

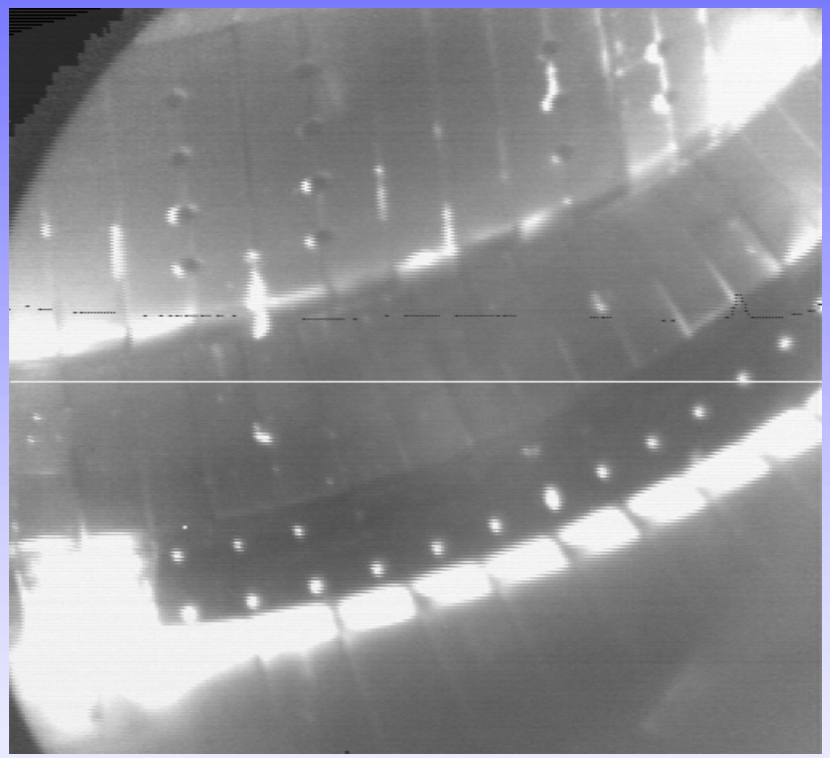
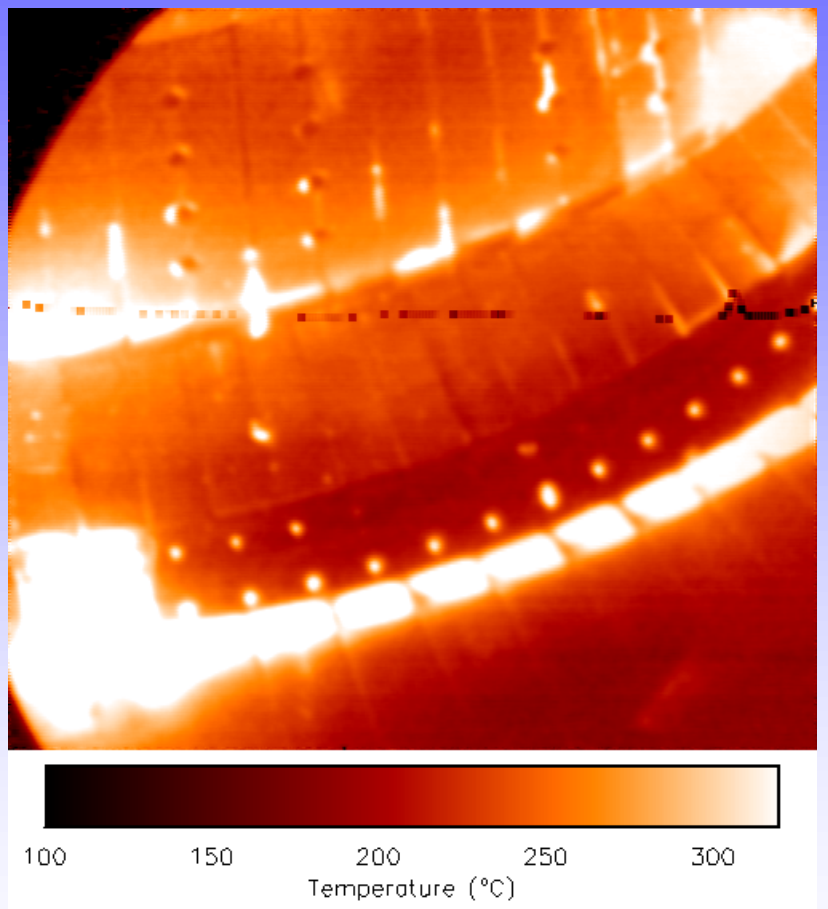


Image obtained with Amber Radiance 1 IR camera using the 4.28-4.42 μm bandpass filter and 1.40 ms exposure



Above 320 ºC, the image is saturated

Heating in a toroidal band also observed after disruption

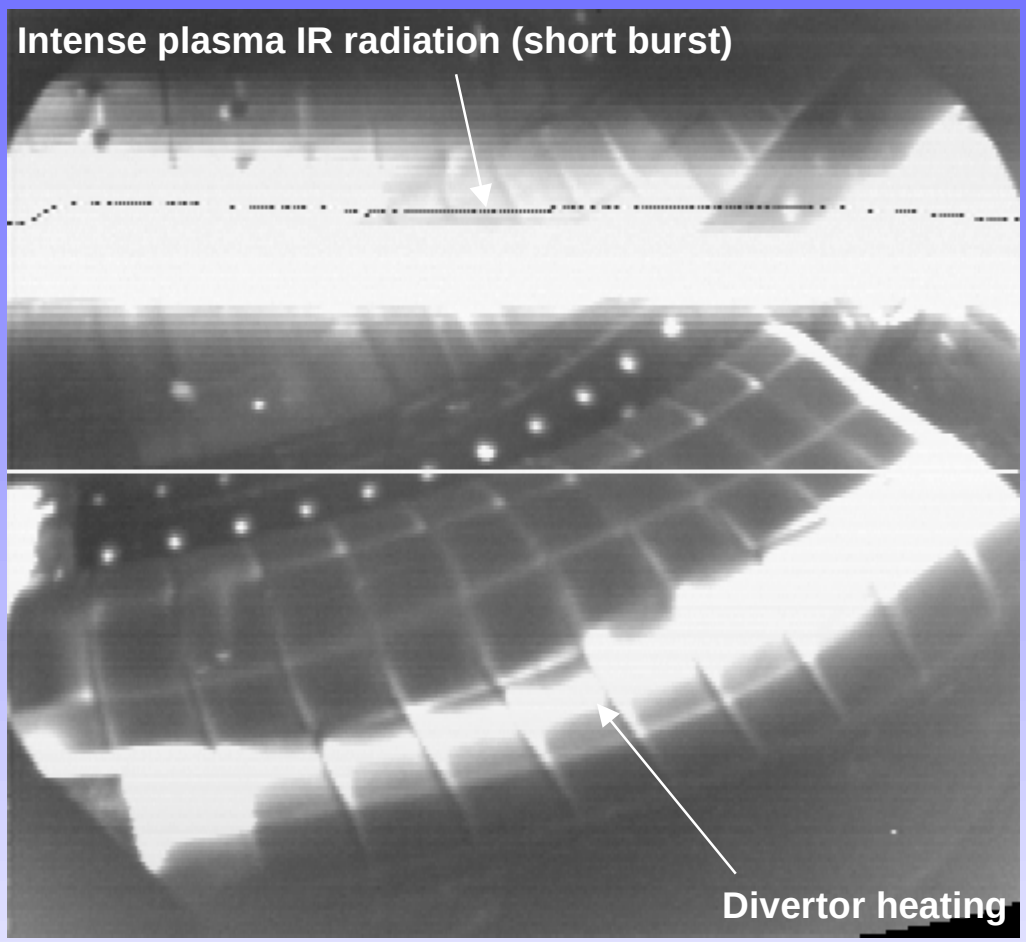
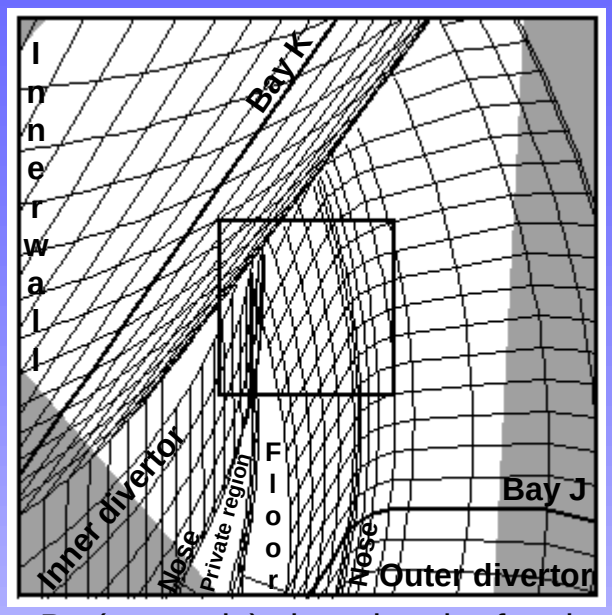


Image obtained with Amber Radiance 1 IR camera using the 4.28-4.42 μm bandpass filter and 0.78 ms exposure

This 0.8 MA disruption resulted in a downward movement of the plasma

Planned improvements

- A new view for the periscope is being proposed, this view (figure at right) will allow the surface below the outer divertor's nose to be imaged.
- A new "all digital" data acquisition scheme will be implemented. This will not only improve the time resolution from 30 Hz to 60 Hz but also improve the dynamic range from 8-bit standard video images to 12-bit images. The new data acquisition system uses a PCI-RCI digital video Remote Camera Interface with 1.25 GBd fiber optic link (EDT, Beaverton, Oregon, USA.). In this way photon counts are directly recorded without the need to deconvolve these counts from image intensities.
- In order to reduce errors in the determination of the temperatures the camera will be cooled down by means of a water chiller and the thermocouples on Alcator C-Mod will be re-commissioned. Error are expected to drop below the 10 ºC level (in the 250 ºC range).



By (remotely) changing the focal length of dual field of view lens on the IR camera from 75 mm to 250 mm, the section within the central square can be magnified.